LOW SILL TESTED FOR TOTAL SEDIMENT-LOAD MEASUREMENT

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LOW SILL TESTED FOR TOTAL SEDIMENT-LOAD MEASUREMENT

By Neil L. Coleman and W. M. Ellis[1]

ABSTRACT

A simple low sill was evaluated for possible use as a field station for measuring sediment load in conjunction with the U.S. DH–48 hand sampler. During steady flow, a cyclic scour and fill effect at the sill caused large local variation in sediment load, resulting in observed sediment-load values about 1.8 times the values obtained using a standardized sampling device to measure total sediment load in the test flume. The sill was judged unsatisfactory on this basis.

INTRODUCTION

For many years various agencies of the Federal Government have carried on field studies of alluvial channels, largely to determine how much sediment is carried by rivers and streams as a result of agricultural practices or urbanization in the contributing watersheds. The U.S. DH–48 hand sampler, which was developed under the auspices of the Federal Interagency River Basin Committee (*5*),[2] is one of the devices most commonly used in these studies for measuring sediment-transport rates.

As shown in figure 1, the DH–48 sampler has a body containing a pint (0.473 liter) milk bottle into which a sediment and water sample is admitted through a nozzle. This device is designed to be used in the equal transit rate (ETR) sampling method, in which the sampler is lowered from the water surface to the streambed and then immediately raised, all at a uniform rate. This results in the collection of a depth-integrated sample that can be used to define the average sediment concentration in the vertical that was sampled. Repeating the process at several verticals spaced across the stream provides a width-depth integrated sample from which the average sediment concentration in the channel cross section — hence the total sediment load — can be found.

Figure 1 shows that the configuration of the sampler body precludes sampling the lower 0.3 ft (91.4 mm) of a stream with a flat bed. In the unsampled zone next to the streambed, a large amount of material is moving by traction and saltation, as well as in suspension. In the field, it is rare to find a flat streambed, and the existence of unsampled zones depends largely on the accidental proximity of the sampler to dunes or other bed features. Under these conditions the accuracy of sampler measurements becomes highly variable.

To find a solution for this problem, experiments have been done in which the total sediment-transport rate was measured at special structures installed in streams. The turbulence flume used by Hubbell and Matjeka (*6*) on the Middle Loup River consisted of an upstream section containing eddy-producing baffles to throw all the sediment into suspension and a downstream sill arranged to allow the nozzle of a DH–48 sampler to traverse the entire flow depth, doing away with the unsampled zone. The design of this turbulence flume was the subject of a careful series of model tests by Benedict, Albertson, and Matjeka (*1*) in which the optimum form and location of the baffles and the end sill were determined. The investigation of Bowie, Bolton, and Murphree (*2*) was carried

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[1] Geologist and hydraulic engineer, USDA Sedimentation Laboratory, Agricultural Research Service, Oxford, Miss. 38655.

[2] Italic numbers in parentheses refer to items in "Literature Cited" at the end of this publication.

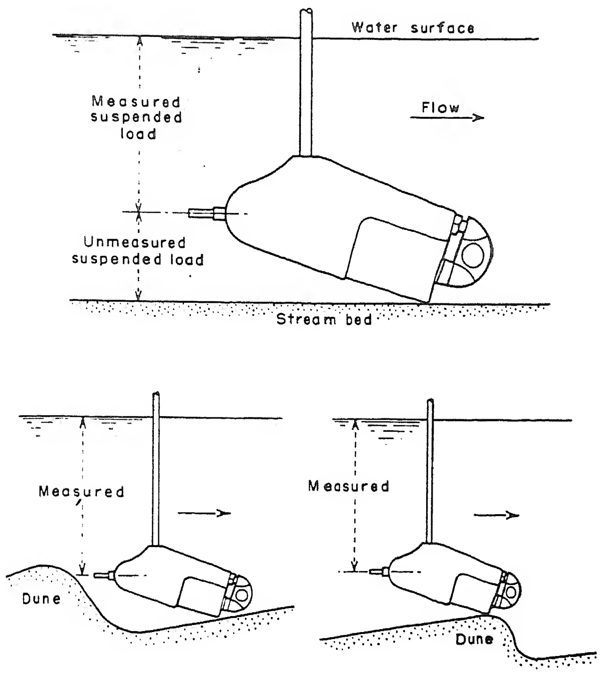

FIGURE 1.—U.S. DH–48 hand sampler.

out on a sheet-pile drop structure that performed essentially the same function as the downstream sill of the flume.

Both of the above structures were elaborate and represented a major installation in the channel bed; installation of the drop structure caused considerable initial disturbance of the channel. The obvious need was for a structure useful for total sediment-load measurement, cheap to construct, and easy to install that would produce minimal disturbance to the natural stream profile. A simple low sill with a crest elevation not greatly different from that of the surrounding streambed appeared to be one structure that would fit the requirements; a series of laboratory experiments was carried out to test the utility of such a sill for total sediment-load measurement.

THE EXPERIMENTAL PROGRAM

The 50-month field study of Bowie, Bolton, and Murphree (*2*) showed that even when the unsampled zone is eliminated, measurement is complicated by the fact that a steady discharge condition exists infrequently, so that the investigator has varying frequencies of opportunity to make measurements at any particular discharge. Furthermore, even for a particular steady discharge, factors such as turbulence and intermittent local scour at the structure cause time-dependent fluctuation of the sediment-transport rate as measured at the structure. The laboratory tests were planned so that the utility of the sill could be evaluated under conditions of steady discharge with continuous sediment transport. The purposes of the experiments were to compare the apparent total load as measured at the sill with the true total load in the channel containing the sill and to compare the degree of variability inherent in sill measurements with that inherent in measurements made at a normal channel section.

Achieving these ends required that the experiments be done in a recirculating flume with an independent total-load measuring device to provide a standard of comparison for the sill measurements. The accuracy of total-load devices is always open to question, and unfortunately there is no practical way of testing such a device in a recirculating flume. However, if measurements are made under particular flow conditions with a given device in a given flume and if these agree with measurements made with several other devices in different flumes with the same flow conditions, this constitutes indirect evidence that the measuring device under consideration is accurate.

The 100-ft (30.5-m) USDA Sedimentation Laboratory flume used by Stein (*8*) and by Willis and Coleman (*9*) has a sampling device that removes a presumptive total-load sample from a vertical-flow section of the circulating system. Stein (*8*) used total sediment loads obtained with this device to calculate experimental Φ_* values ($\Phi_* =$ Einstein's sediment load number) that agreed with Einstein's theoretical Φ_*—ψ_* function ($\psi_* =$ Einstein's hydraulic number) as well as the original experimental values Einstein (*4*) used to verify the function. Willis and Coleman (*9*) found that the device gave results that were in substantial agreement with results obtained by other workers with other types of equipment in other flumes. These facts led to the adoption of the 100-ft flume for the sill experiments.

Figure 2 shows the recirculating flume. It is 100 ft (30.5 m) long, 4 ft (1.22 m) wide, and 2 ft (0.61 m) deep. Its pumping capacity is 17.5 ft^3/s (0.5 m^3/s). Discharge is measured by a venturi meter in the return pipe under the flume channel. The equipment for measuring the

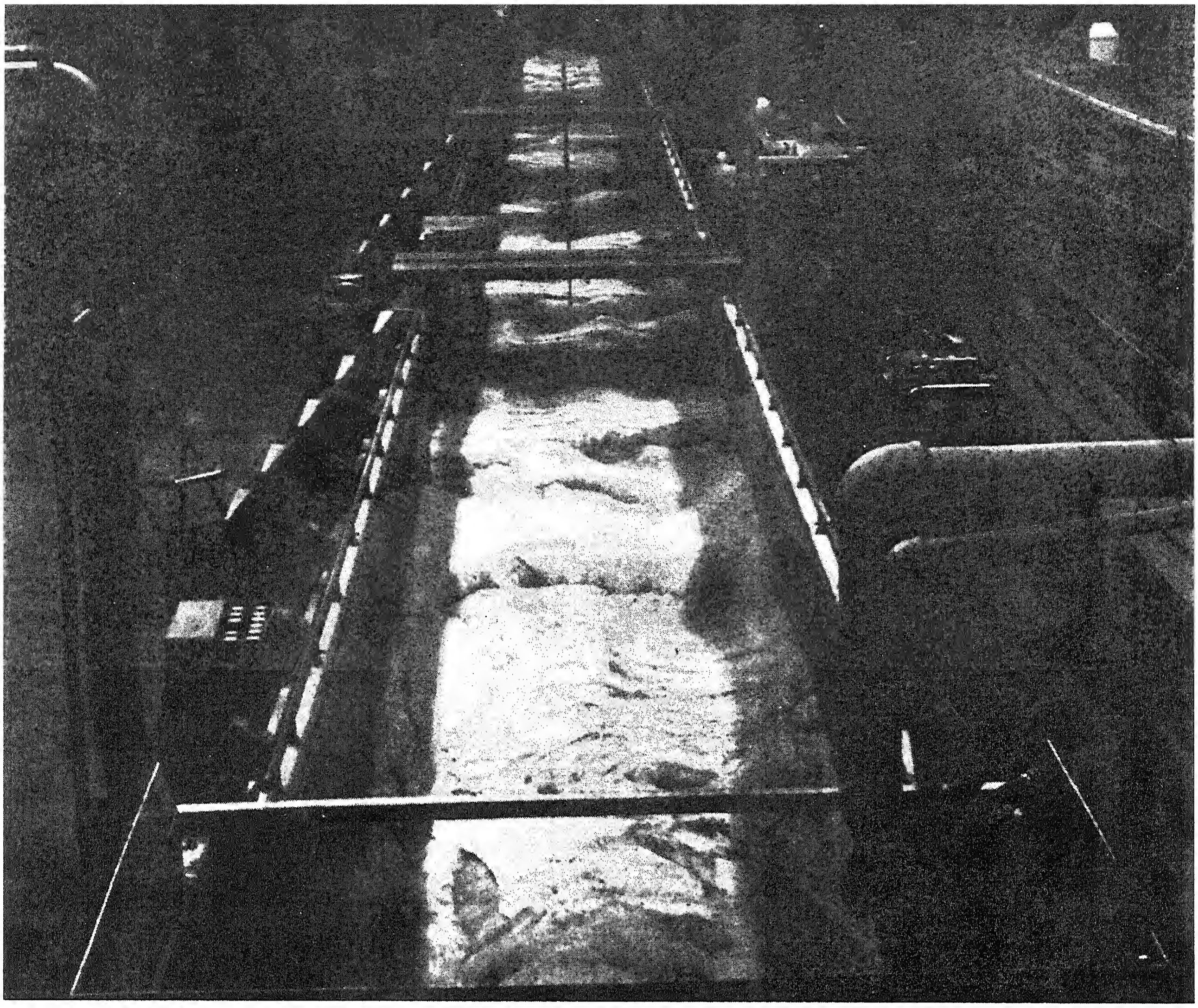

FIGURE 2.—Experimental apparatus installed in the 100-ft flume at the USDA Sedimentation Laboratory.

total sediment load includes an automatic traveling-slot sampler in the rectangular vertical-flow section between the return pipe and the channel. The sampler is moved continuously back and forth across the flow section by a hydraulic device, while a pump withdraws sediment-water mixture through the slot and transmits it to a settling tank, where the sediment is retained. A second pump returns the water to the flume. Appropriate valves and a flow meter control the intake velocity at the slot so that it can be equalized with the average velocity in the rectangular conduit. By operating this sampler for a known number of hours and weighing the sediment retained in the tank, the time-average transport rate may be calculated.

The sill was installed in the flume channel 75 ft (22.8 m) below the entrance. It was made of pine lumber, with a piece of aluminum structural channel for a crest, and stood 0.75 ft (22.9 mm) high installed in the channel. As shown in figure 2, a bridge across the flume permitted the taking of measurements at the sill with a DH–48 sampler. A second bridge was located so that measurements could be made at a normal section 25 ft (7.6 m) upstream.

Experiments were carried out with two sediments having median diameters of 0.1 and 0.44 mm. Cumulative size distributions for these materials are shown in figure 3. The discharge

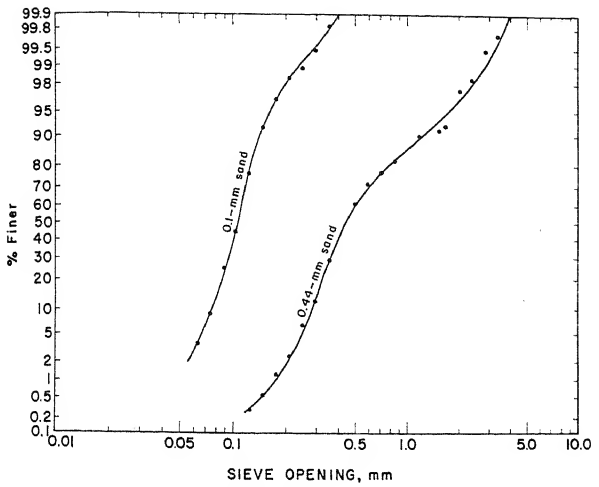

FIGURE 3.—Size distributions of the sands used in the experiments.

range for the experiments was approximately 3 to 6 ft^3/s (0.08 to 0.17 m^3/s). Sediment concentration varied from 30 to 10,000 parts per million.

In the experiments, the flume was operated at a selected depth and discharge long enough for the sand bed to come to an equilibrium slope and for full continuity of sediment transport to be established. The automatic total-load measuring device was then started and run continuously for a number of hours to obtain a long-term time average sediment-transport rate, which was used as the standard for the experiment. Measuring times depended on how rapidly sand accumulated in the settling tank, and this in turn depended on the sampler intake rate and the discharge in the flume. The measuring times varied from about 3 hours for the high flows to about 18 hours at the lowest flows.

Concurrently with standard total-load measurement, the DH–48 sampler was used to take samples at both the sill and the normal section. At each location, ETR samples were taken at seven verticals spaced 0.5 ft (152.4 mm) apart across the 4-ft width of the flume. In each case, the same bottle was used for all seven depth integrations so as to secure a single width-depth integrated sample for the whole flow cross section. The sediment concentration determined from this sample was used to calculate the apparent sediment-transport rate. Samples were taken at the sill and the normal section at 15-minute intervals for a period of 8 hours, to define the time variation of the apparent sediment-transport rate as measured at the two locations.

RESULTS AND ANALYSIS

Thirty-seven experiments were completed. The general flow conditions of these experiments are summarized in table 1. The total sediment loads were calculated from the weights of sand retained in the collection tank of the automatic total-load measuring device at the end of each experiment.

The ETR samples taken at the normal section during each experiment provided a series of individual determinations of measured sediment load from which an average measured sediment load could be calculated. The standard deviation of the individual determinations was also calculated. In table 2, the average measured sediment load and the coefficient of variation (ratio of standard deviation to mean) are given, together with the associated flow conditions.

In figure 4, the average measured sediment load L_N at the normal section has been plotted against the true sediment load L_T as determined with the automatic total-load measuring equipment. The graph indicates that the measured load at the normal section corresponded to the total load at the lower discharges. These were flows in which dunes occurred on the bed. At the higher discharges, where the bed was either flat or in the antidune regime, the measured load tended to be less than the total load.

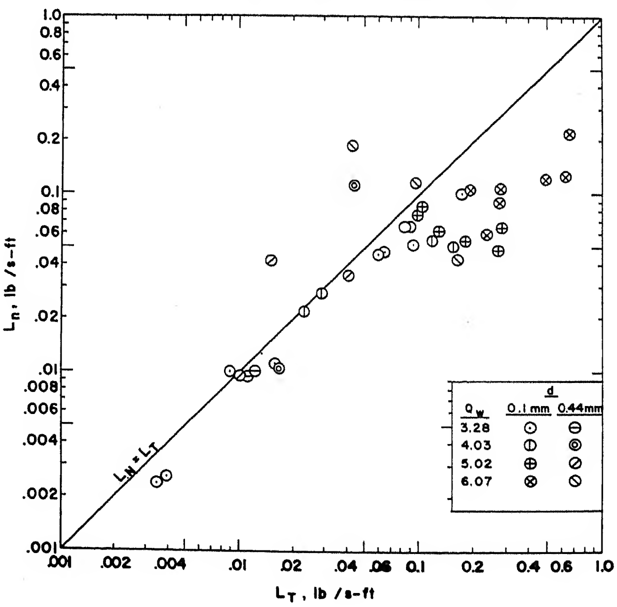

FIGURE 4.—Average measured sediment load at the normal section compared with true total sediment load.

TABLE 1.—*General flow conditions*

Test No.	Sand size (mm)	Discharge (ft³/s)	Temperature (°F)	Total sediment load (lb/s/ft)
1	0.10	3.28	76	0.093
2	.10	3.28	75	.060
3	.10	3.28	74	.064
4	.10	3.28	78	.017
5	.10	3.28	78	.010
6	.10	3.28	78	.016
7	.10	3.28	78	.004
8	.10	3.28	78	.004
9	.10	4.03	75	.154
10	.10	4.03	74	.120
11	.10	4.03	74	.088
12	.10	4.03	78	.085
13	.10	4.03	76	.029
14	.10	4.03	76	.023
15	.10	5.02	74	.285
16	.10	5.02	74	.269
17	.10	5.02	78	.180
18	.10	5.02	76	.129
19	.10	5.02	76	.098
20	.10	5.02	75	.104
21	.10	6.07	72	.622
22	.10	6.07	73	.488
23	.10	6.07	73	.656
24	.10	6.07	79	.234
25	.10	6.07	75	.280
26	.10	6.07	75	.273
27	.10	6.07	74	.191
28	.44	3.28	76	.012
29	.44	3.28	79	.002
30	.44	4.03	79	.044
31	.44	4.03	77	.016
32	.44	5.02	79	.101
33	.44	5.02	76	.041
34	.44	5.02	76	.016
35	.44	6.07	78	.172
36	.44	6.07	77	.096
37	.44	6.07	70	.043

Coleman (*3*) demonstrated the cause of the relationship between measured load and total load that appears in figure 4. When an ETR sample is taken in a flow with dunes on the bed, the unsampled zone postulated in the original theory of the sampler (*5*) may not exist; rather, the position of the sample nozzle at the bottom of the path varies relative to the crest of a dune. In one typical sample taken during steady discharge in the vicinity of an individual dune as it propagated downstream, the sampler nozzle stopped at a point just proximate to the dune crest, so the entire flow depth was sampled, giving a sediment concentration of 6,492 parts per million. In another path, the sampler struck behind the dune crest, leaving a sizable zone unsampled. The sediment concentration was 421 parts per million. In a third path, in which the sampler nozzle penetrated the dune front at the lowest point, the sediment concentration was 17,463 parts per million. All three of these, as well as other possible sampling events, take place in a rather random way during the course of normal ETR sampling. Thus, in flows with dunes, sampling errors tend to be compensating, and the measured load tends to approximate the total load. In flows with flat bed or antidune conditions, an unsampled zone always exists, and the measured load always tends to be less than the total load.

The ETR samples taken at the sill during the experiments were treated in the same way as those taken at the normal section. The average sediment load measured at the sill and the coefficient of variation for each series of measurements are given in table 3.

In figure 5, the sediment load L_S measured at the sill has been plotted against the total load L_T. The results contrast with those obtained at the normal section; L_S is always higher than L_T. The line of best fit to the data lies substantially above the equality line in the graph, so that $L_S = 1.8 L_T$. The cause for this consistent bias is

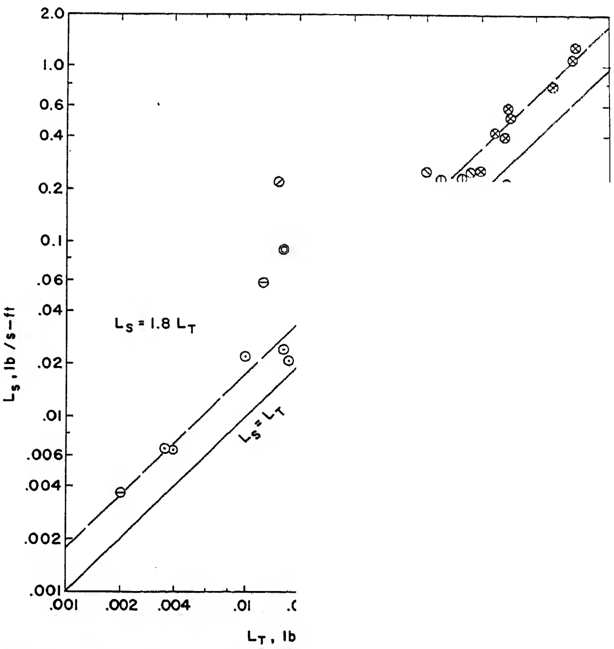

FIGURE 5.—Sediment-load
compared with the to

TABLE 2.—*Summary of measurements at the normal section*

Test No.	Sand size (mm)	Discharge (ft^3/s)	Depth, normal section (ft)	Load, normal section (lb/s/ft)	Coefficient of variation
1	0.10	3.28	0.521	0.052	0.112
2	....	....	.516	.046	.859
3	....	....	.512	.048	.054
4	....	....	.634	.010	.416
5	....	....	.636	.011	.112
6	....	....	.635	.012	.104
7	....	....	.756	.002	.158
8	....	....	.737	.002	.116
9	....	4.03	.437	.062	.104
10	....	....	.435	.056	.455
11	....	....	.603	.066	.103
12	....	....	.608	.066	.101
13	....	....	.731	.021	.090
14	....	....	.716	.022	.091
15	....	5.02	.443	.065	.129
16	....	....	.445	.049	.152
17	....	....	.541	.055	.315
18	....	....	.603	.062	.236
19	....	....	.685	.078	.249
20	....	....	.696	.085	.364
21	....	6.07	.483	.125	.131
22	....	....	.476	.121	.110
23	....	....	.457	.220	.194
24	....	....	.538	.060	.096
25	....	....	.539	.109	.125
26	....	....	.625	.090	.196
27	....	....	.652	.107	.210
28	.44	3.28	.510	.010	4.147
29	....	....	.630	.001	.875
30	....	4.03	.436	.113	2.415
31	....	....	.605	.011	9.528
32	....	5.02	.442	.096	3.011
33	....	....	.576	.036	.718
34	....	....	.542	.042	3.059
35	....	6.07	.470	.044	.858
36	....	....	.532	.116	2.239
37	....	....	.748	.186	2.166

believed to be a cyclic scour and fill action observed in the vicinity of the sill during all experiments.

Figures 6 and 7 show the scour and fill phases of the cycle, respectively. In the scour phase, a gentle depression formed below the sill, while a pronounced scour hole at the upstream face of the sill continuously threw heavy plumes of sand into suspension. This sand passed over the sill along with the normal sediment load and settled to the streambed in the downstream depression. As figure 6 shows, during the scour phase the DH–48 sampler integrated the total flow depth over the sill. Thus, the sediment-load measurement at the sill included both the total load and the excess sediment removed from the scour hole and transported only locally. Figure 7 shows the fill phase of the cycle, in which the sill was completely buried; integration of the total flow depth was impossible, and a sediment-load measurement included only part of the total load.

In all experiments, the scour part of the cycle lasted longer than the fill phase. Thus, in a series of measurements taken at regular 15-minute intervals for some hours, more than half the measurements indicated excess sediment load, making the calculated average higher than the total load, as shown in figure 5.

Comparison of the coefficients of variation σ_S/L_S and σ_N/L_N of measurements at the sill and

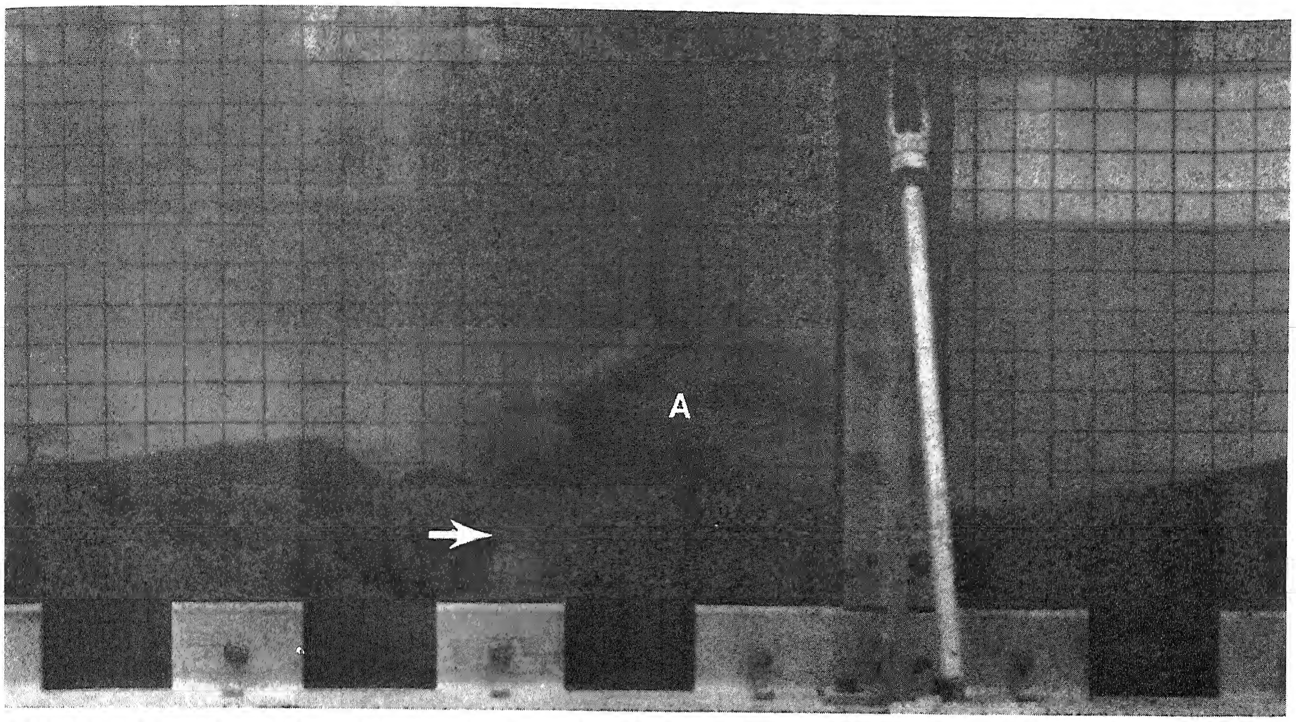

FIGURE 6.—Operation of the sill (arrow) and sampler during the scour phase. $Q=4.03$ ft^3/s. Velocity=2.04 ft/s.

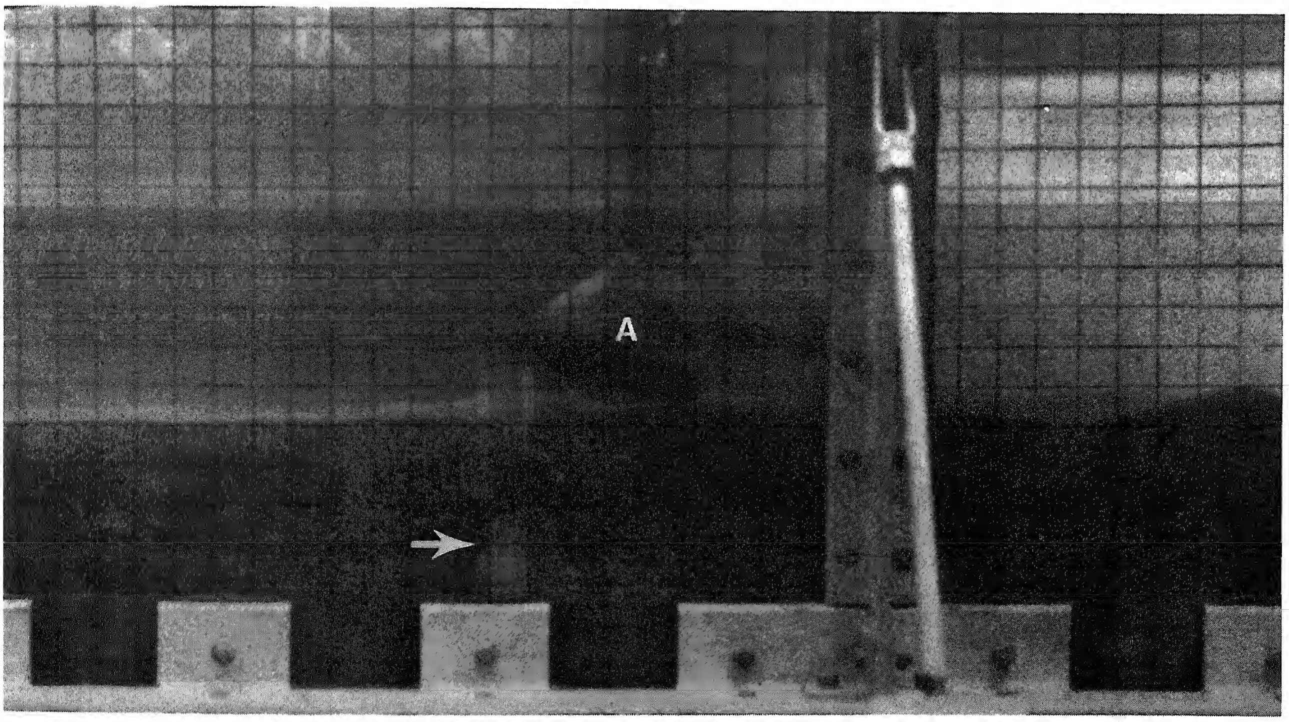

FIGURE 7.—Operation of the sill (arrow) and sampler (A) during the fill phase. $Q=4.03$ ft^3/s. Velocity=2.04 ft/s.

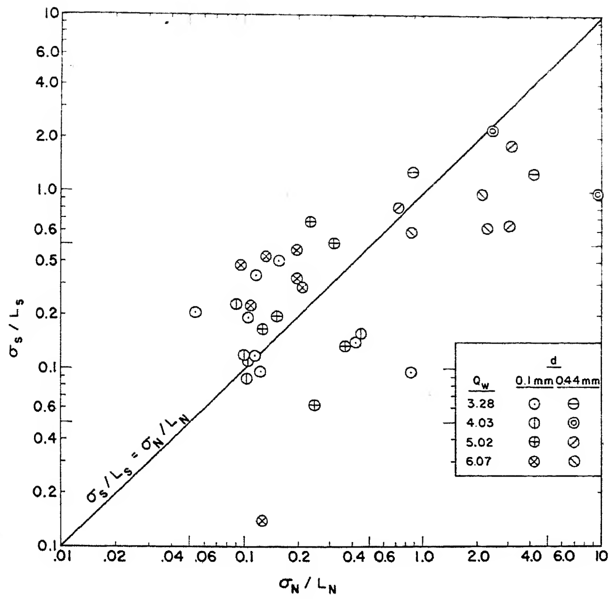

FIGURE 8.—Comparison of coefficients of variation of sediment-load measurements at the sill and the normal section.

the normal section respectively is shown in figure 8. The data scatter broadly about the line of equality in the graph, indicating, as would be expected, no causal correlation between σ_S/L_S and σ_N/L_N. However, the plot indicates that the variation in the sill measurements is no different in order of magnitude from that in the measurements at the normal section.

CONCLUSIONS

Tests of a simple low sill as a total load measuring station for field use showed that scour in the immediate vicinity of the sill caused inaccurate measurements of total load. The average sediment load measured at the sill with a DH–48 sampler was on the order of 1.8 times the average sediment load actually carried by the channel under any particular set of flow conditions. In contrast, the average sediment load measured with the same sampler at a normal channel section tended to correspond to the total load for

TABLE 3.—*Summary of measurements at the sill*

Test No.	Sand size (mm)	Discharge (ft^3/s)	Depth, sill (ft)	Load, sill (lb/s/ft)	Coefficient of variation
1	0.10	3.28	0.408	0.093	0.096
2	....	....	.407	.089	.096
3	....	....	.405	.084	.206
4	....	....	.516	.021	.144
5	....	....	.520	.022	.119
6	....	....	.514	.024	.191
7	....	....	.624	.006	.400
8	....	....	.620	.006	.333
9	....	4.03	.386	.237	.112
10	....	....	.386	.231	.157
11	....	....	.504	.141	.088
12	....	....	.506	.129	.118
13	....	....	.613	.050	.228
14	....	....	.614	.048	.228
15	....	5.02	.416	.526	.169
16	....	....	.408	.401	.199
17	....	....	.497	.151	.514
18	....	....	.524	.126	.668
19	....	....	.612	.133	.062
20	....	....	.609	.156	.134
21	....	6.07	.378	.166	.429
22	....	....	.398	.794	.224
23	....	....	.394	.372	.471
24	....	....	.499	.430	.389
25	....	....	.490	.588	.014
26	....	....	.626	.220	.324
27	....	....	.616	.260	.292
28	.44	3.28	.399	.060	1.271
29	....	....	.510	.004	1.297
30	....	4.03	.378	.081	2.251

TABLE 3.—*Summary of measurements at the sill*—Continued

Test No.	Sand size (mm)	Discharge (ft^3/s)	Depth, sill (ft)	Load, sill (lb/s/ft)	Coefficient of variation
31	....	....	.494	.091	.996
32	....	5.02	.383	.135	.649
33	....	....	.475	.156	.818
34	....	....	.583	.223	1.845
35	....	6.07	.373	.254	.596
36	....	....	.468	.254	.268
37	....	....	.587	.206	.960

flows with dune regime and to be lower than the total load in flat-bed and antidune flows. The coefficients of variation of sequences of measurements taken at the sill and at the normal section proved to be of the same order of magnitude. On the basis of the observed results of measurement with a DH–48 sampler at a low sill, it is recommended that this sort of structure not be incorporated into field installations for total-load sediment measurement.

LITERATURE CITED

(1) Benedict, P. C., Albertson, M. L., and Matjeka, D. Q. 1955. Total sediment load measured in turbulence flume. Trans. Am. Soc. Civ. Eng. 120: 457–484.

(2) Bowie, A. J., Bolton, G. C., and Murphree, C. E. 1972. Direct measurements and computations of total sediment discharge. Trans. Am. Soc. Agric. Eng. 15 (1) : 91–98.

(3) Coleman, N. L. 1962. The behavior of a DH-48 hand sampler among sand dunes. Ole Miss Eng. 2 (4) : 6–8.

(4) Einstein, H. A. 1950. The bed-load function for sediment transportation in open-channel flows. U.S. Dep. Agric. Tech. Bull. No. 1026, 71 pp.

(5) Federal Interagency River Basin Committee. 1952. The design of improved types of suspended sediment samplers. Report No. 6, 103 pp.

(6) Hubbell, D. W., and Matjeka, D. Q. 1959. Investigations of sediment transportation, Middle Loup River at Dunning, Nebraska. U.S. Geol. Surv. Water Supply Pap. 1476, 187 pp.

(7) Miller, C. R., and Bowie, A. J. 1965. Sediment sampling: Instrumentation and techniques. Trans. Am. Soc. Agric. Eng. 8 (2) : 267–274.

(8) Stein, R. A. 1965. Laboratory studies of total load and apparent bed load. J. Geophys. Res. 70 (8) : 1831–1842.

(9) Willis, J. C., and Coleman, N. L. 1969. Unification of data on sediment transport in flumes by similitude principles. Water Resour. Res. 5 (6) : 1330–1336.

*1976-G.P.O. 1750S 671-583/41